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Method to enable LCA analysis through each level of development of a BIM model

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Abstract

Whole Building life cycle assessment (LCA) calculations are increasingly done using building information modeling (BIM) data exports, but some challenges need to be overcome. BIM models lack data for a whole building LCA analysis. To counter this lack of detailed information, manual inputs are often required when using a static BIM model and cannot easily consider recalculations over the duration of the project. This paper presents a method to automatically perform LCA calculations early, at the first level of a BIM model's development (i.e. the LOD100 level), and to allow for easier updates of the calculation throughout the evolution of the BIM model. To achieve this goal, a novel data layer and format is proposed. This data layer fills the information gap between extracted BIM data and existing LCA data provided by common LCA databases such as ecoinvent.

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Keywords: building information modeling; level of development; life cycle assessment; sustainable buildings; automated LCA calculations

1. Introduction

The construction domain is currently experiencing a paradigm shift. Rather than concentrating only on its initial construction cost, project stakeholders increasingly give importance to the value of the building [1,6]. This new paradigm creates the need to assess the environmental impacts of a future project, but, with the current life cycle assessment (LCA) way of expressing results, this is difficult to understand for non-expert. Moreover conducting a

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LCA requires a lot of effort [6,9]. Consequently, LCA tools are rarely used [12]. This paper presents a new data layer and format to better enable the automation of the LCA process and ease the effort related to making modifications to the LCA model throughout the design process of a building.

2. Literature review

2.1. Information delivered by the BIM model

The emerging building information modeling (BIM) technology enables an iterative three dimensional (3D) modeling process and numeric representation for designing and building [7]. According to experts, this technology should start to be used at the early onset of building design projects [8,14]. During each project design iteration, this 3D building model evolves and becomes more accurate as it acquires more and more information. The level of information detail included in a BIM model, and its corresponding available data, is described by the term "level of development" (LOD) as described by the BIMForum [5] :

Table 1. LOD definition from BIMForum and data available [5]

LOD	Definition	Data available
100	The element is represented with a generic representation	Building approximate size and volume
200	The element is represented with a generic object	Approximate size and shape
300	The element is represented as a specific object without a specific assembly	Size and shape
350	The element is represented as a specific object with a specific assembly	Size, shape and assembly detail
400	The element is represented as a specific object with a specific assembly and with the installation detail	Size, shape, assembly detail and installation detail
500	The element is a field verified representation	Size, shape, assembly detail and installation detail

As it can be seen in Table 1, each LOD level should include progressively more detailed data in its corresponding BIM model. For example, in the Autodesk Revit BIM software, this information can be obtained from the following entities: object, object's type (sometimes referred to as object's classes) and the building material itself. An object in a BIM model represents a real life object with all of its specific properties. All objects included in a BIM model are associated to an object's type. The object's type regroups all the common rules and parameters of a group of objects, for example: a wall assembly. A very useful property of an object type is that it allows the building designer to change it in one location, and this change is reflected in all of the linked objects in the corresponding 3D model. Another important information needed in a BIM model is the building material itself. To accurately describe an assembly in an object's type, the designer, needs to specify every layers of a material and specify the thickness of these layers.

2.2. Previous work on BIM-LCA integration

Life cycle assessments (LCA) in the construction industry are used to assess the potential environmental impacts of a product [10,11]. They are rarely used today to assess the environmental impacts of an entire building [12]. This is mainly because the LCA requires a lot of detailed information to be entered manually, which can be very time consuming [6,9,16]. The minimum level of data required to conduct an LCA are the quantities of every significant material item required for the building as well as the amount of energy to operate the building [14]. A well-detailed BIM model could be used as the main information source to perform this calculation [9,13,16,17]. This is because the 3D model is rich in information and it is relatively easy to export the required data in its numeric form [17]. While it is easy to extract the data, a reported challenge is that the LCA calculations often require the need of an expert to interpret the data [6] and it can become difficult to compare results to similar projects [9]. Documented complaints have emerged also stating that the LCA process does not have a concrete method to calculate LCA for entire buildings [6]. This concern is beginning to be addressed by standards such as ISO 14040 [11], ISO 14044 [10] and ASTM E2921 [2] where the requirements to achieve an LCA for a whole building have started to be defined. At the time of the writing of this paper, no method clearly addresses the LCA calculation based on LOD100 [15] and only a few publications [3,6,8,15] discuss this need.

3. Convert BIM model to LCA model

The overall goal of our proposed method is to automatically perform LCA calculations early, i.e. at the first level of a BIM model's development (the LOD100 level), to allow for easier updates of the calculation throughout the evolution of the BIM model. To achieve this goal, our proposed solution requires taking into consideration a number of challenges that designers have today when conducting an LCA for a whole building. First, an ideal method should minimize manual entry. Also, the resulting LCA model used for calculation should be easy to understand, modify and explore by a building designer. Next, this LCA model should be linked to the BIM model but should not force a change to the BIM model automatically. This characteristic would enable the designer to test many design options without affecting his initial solution. To achieve these usability characteristics, the proposed approach is to breakdown the LCA model into two parts: 1) generate the process tree structure required by the LCA calculation; and 2) fill the data gap to complete the LCA calculation at an early stage of design (e.g. LOD100).

3.1. Process tree structure

ISO recommends describing the analyzed product with a set of unit processes that are linked with each other using flows [10,11]. A unit process is the smallest element that quantifies the amount of input required to accomplish an action that produces the desired output [10,11] (e.g. using a building X for Y years). Together, the sets of units form a tree that describes the product's lifecycle. We observe that a typical BIM model for an entire building is very rich in information and can contain thousands of objects. This can make it very hard for a building designer to handle so many unit processes at a time. To allow for a better usability, the model would need to break down this information into manageable and logical groups. Our proposed solution would be to regroup the BIM information using its Uniformat II code (see Figure 1). As we have discussed, the BIM model information is typically contained in three types of entity: an object, an object's type and the material linked to the object's type.

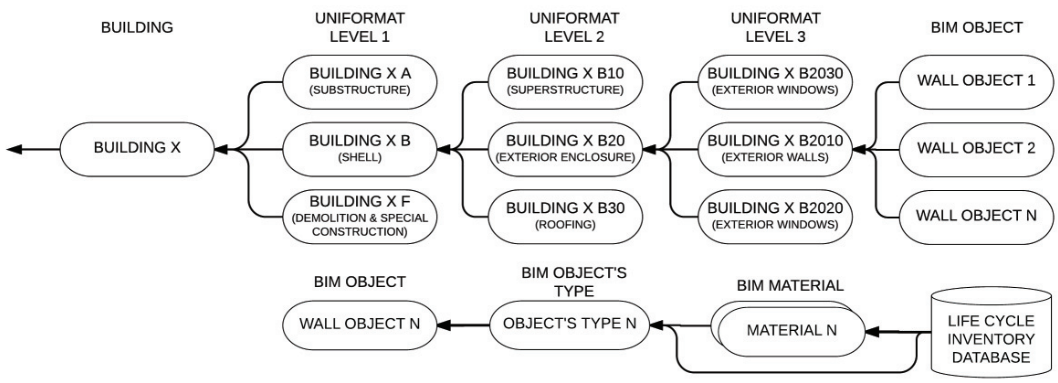

Figure 1: Process tree structure

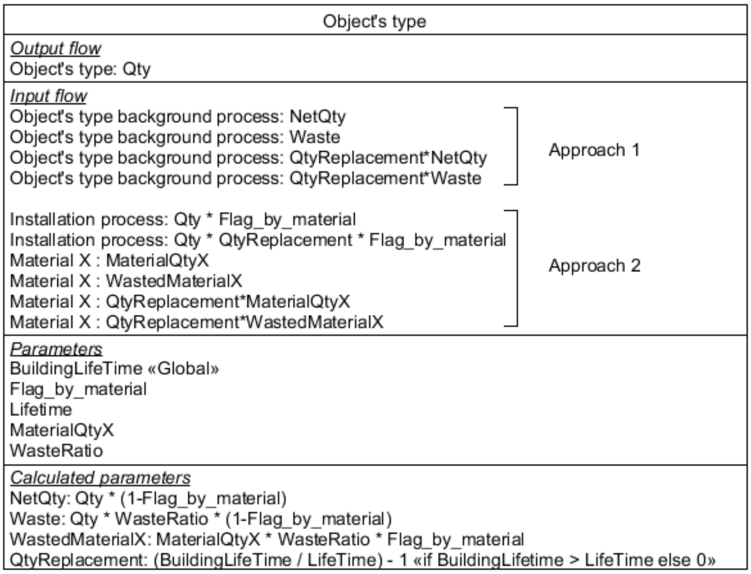

Figure 2: Object's type unit process

In the LCA model, these three entities will be converted to unit processes. First, the BIM object process is a unit process that contains only the object quantity. Then, in order to create as much independence as possible between the LCA model and the BIM model, the quantity will be expressed in each measurement available in the model, such as: the volume, the area, the weight, the length, the width and the height.

To describe material extracted from BIM, the system automatically creates a unit process with the material as an output and an input that links to a process available in the life-cycle inventory database (background process) with the same name of the material that describes its production and its disposal. When the system fails to automatically link the unit process to a background process, the user will need to describe it manually. Without creating a unit process for material, each material would be described directly in the object type's unit process. In the case of a manual modification (e.g. wood's unit process is automatically linked to the wood production but for another country), the user would have to find and change all this material input in each object's type unit process that uses it, one by one. The object's type unit process contains the information about the life cycle of the object's type and its assembly. The output is the object's type specified by the BIM model and these inputs will vary depending on the data available in the model (see Figure 2).

For an element that has all the required data (i.e. quantities, assemblies, quantities for each assembly) an object's type unit process can be described in two ways. First, the process could be linked directly to one or many background processes in order to describe the production and the disposal of this type of object. Alternatively, the object's type could be described by using its material unit process and its installation unit process. An installation unit process describes the process to assemble all the materials together. With this approach, all the material unit processes are automatically generated and quantified because a complete BIM model should have this level of detail. These two options could be made available by using a simple flag in the unit process (see the Flag_by_material in Figure 2). This flag can be set to "1" to use only material processes; otherwise, the flag can be set to "0".

These two approaches to describe an object's type have a common element: the input for the replacement and the waste generated during the installation is separated from the initial construction. By discerning them individually, the user will then be able to know which life-cycle step had the most impact for the project. This design proposal is the cornerstone of our proposed method to allow the user to modify the LCA model easily and more importantly, enables all “common changes” to be applied for building design simulations without having any impact on the associated BIM model. This design proposal will also enable the user to change the type of an object with another type by only changing the input to this object. Finally, this design proposal will allow the user to change the object’s type by simply adding and removing material unit processes or by adding only one input of another object’s type unit process.

4. Filling the data gap between converted BIM data and background data

In an ideal BIM model, every data element should be at least at the LOD350 detail level for the most accurate LCA results. In reality, a BIM project model contains many data elements at different LOD detail levels and this, throughout all design process stages. Each object at a lower LOD level than LOD350 will be missing essential data elements that would improve an LCA calculation (see Table 2).

Table 2. Information needed to perform LCA

LOD	Missing information
100	All information, except global information on the building
200	The Specific object’s type
300	The assembly description

Berg [4] reveals that the LOD100 level of data is not suitable for standard LCA calculations, however it allows for a high level LCA model estimate, with the use of generic data based on similar building with the same context. In the proposed approach, the minimum data to be provided are the location, the use, and, directly from the BIM model, high level building descriptions including total building volume, height and number of stories. Using this information, pre-defined generic object types at the Uniformat II rank 3 level [4] can be identified for the given building type and context. At this point, the model is equivalent to an LOD200 level. The linking to specific and fully described object types is then based on the probability that a given object type could be used in the given building. This requires the accumulation of information on the object types actually being used in a given context.

A key aspect of the approach is that this uncertainty is to be reflected in the calculation results. These generic object’s types unit process contain inputs to specific object’s types Generic data on the generic object types , but with the use of uncertainty and statistic, an LCA model could be estimated with a certain level of precision. To use LOD100 level of data as an input, there is a need to generate the missing data To enable LCA calculation, as soon as LOD100 level of data, the proposed data design needs to be improved with a new design component that requires processes based on statistic. Thus, when elements are described by these generic process types that then have weighted links to specific process types, the uncertainty resulting from the lack of specific information is propagated to the whole building LCA score using a Monte Carlo simulation approach. The contribution of specific building elements to the overall uncertainty is also calculated, providing the model designer with key information as to which parts of the LCA model contribute most to the uncertainty of the score, and which therefore should be specified in priority to reduce this uncertainty. The described approach, using probability of occurrence of specific object types, can be used for any model component not specifically read from the BIM model or provided by the user.

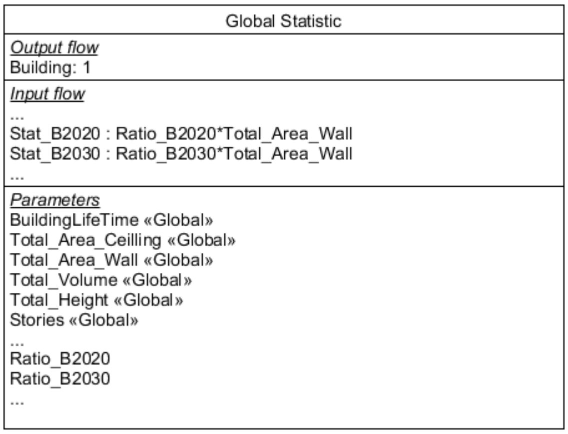

Figure 4: Global statistic process

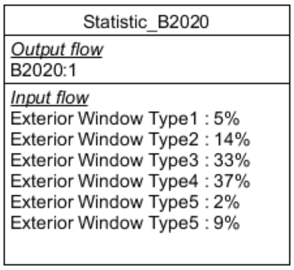

Figure 3: Statistic process for B2020 object's type

To simulate the quantity of a specific object's type, the LCA process regroups all possible specific object's type that have the same Uniformat code as well as the probability that it will be included in this building based on the BIM model data. This calculation process will be different than a typical LCA calculation at the LOD350 level. Using LOD100 level requires us to calculate the uncertainty by choosing only one object's type based on its probability (see Figure 3). With this structure, an automated system can switch to a more specific process with less uncertainty, when the BIM model has new/more information.

5. Conclusion

This paper presents a method to automatically perform LCA calculations early, at the first level of the BIM model's development (i.e., LOD100), and allows for easy updates of the calculation throughout the evolution of a BIM model. To achieve this goal, a novel data layer and format is proposed. In future work, this LCA estimation proposal will be experimented in order to determine its accuracy and reliability to allow for early building design decisions, using data at different LOD levels.

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